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14. ABSTRACT
A brief history of mathematical information and communication theory is presented with examples to illustrate the communications aspects of transmitting and receiving information over a channel. We wish to extend these concepts and modify the messages or information objects themselves and yet maintain the meaning of the messages. Our approach is to reduce the quality of the original messages without severely degrading a message's intent before compressing the resultant messages for transmission over a communications channel. Our motivation is to enhance and improve the efficiency in the delivery and reception of information objects from computational devices with limited bandwidth and processing capability.

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Enhancing the Delivery and Reception of Information Objects Over Deprived Channels and Computational Devices

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Abstract: A brief history of mathematical information and communication theory is presented with examples to illustrate the communications aspects of transmitting and receiving information over a channel. We wish to extend these concepts and modify the messages or information objects themselves and yet maintain the meaning of the messages. Our approach is to reduce the quality of the original messages without severely degrading a message's intent before compressing the resultant messages for transmission over a communications channel. Our motivation is to enhance and improve the efficiency in the delivery and reception of information objects from computational devices with limited bandwidth and processing capability.

Section One Introduction:

U.S. Air Force Major General Ted F. Bowlds has declared that the science and technology vision of the USAF is to "Anticipate, Find, Fix, Track, Target, Engage, and Assess — Anything, Anytime, Anywhere" (AF2T2EA4). Realizing this vision will require the USAF to extend, modify, create, and integrate technologies from many different domains, including communications, sensors, signal processing, artificial intelligence, robotics, computer architectures, and software. The AF2T2EA4 vision will also require that the military manage information delivery both dynamically and securely, getting the right information to the right people who use multiple devices in multiple locations as well as gathering information from them. Managing information delivery includes gathering, storing, and distributing information objects (any collection of digital multimedia data) throughout the Department of Defense (DoD). The US military must provide the right information to its warfighters in a timely manner. This must be done securely, to a large variety of mobile devices across different networks, in different formats, and using multiple protocols. Mobile devices should be used to receive information from the network, gather data, and send it to the network.

There is a significant opportunity available to meet this vision and goals with the advances to hardware and software in both the government and commercial sectors. Technology improvements in networks, computing systems, mobile devices, etc. offer the potential to gather more information and appropriately disseminate it in a timely, efficient, and secure manner. For example, a person in the field can gather important information for performing battle damage assessment with a wireless phone that contains a camera and GPS (global positioning system)

capability. This enables a warfighter on the ground to take images of the results of a missile attack, manually and/or automatically annotate them with metadata such as location, direction, time, user identification, and then transmit them via telephony. The technology is available, but in a military setting there are issues that exist including:

- How do these images get distributed to the right people when it is needed?
- How do these images get transcoded (i.e. modified or transformed) for access on various new and legacy government systems?
- How does the user annotate the images so the recipients can properly assess them?
- How do the recipients search and filter the information they need?
- Can we trust the information and is the information secure in its transmission?

Current commercial products implement some of the technologies that the World Wide Web (W3C) consortium is promoting and facilitating to improve the interoperable usage of multiple types of devices for use within the Semantic Web (the next generation Internet). Its Mobile Web Initiative is defining those standards that address issues in interoperability and usability. They address authoring guidelines, best practices, and device description solutions in a field that is remarkably dynamic.

The military also has technology that addresses elements that are required to realize the AF2T2EA4 vision. Some of these are the Global Information Grid (GIG), and the Net-Centric infostructures that each branch of the military has developed, i.e. USAF's ConstellationNet, the US Army's LandWarNet and the Navy's FORCENet where communities of interest (COI) will share relevant information in a secure and timely manner. The Distributed Common Ground System (DCGS) is a Net-Centric global intelligence sharing network that is also implemented by each service under an overarching DoD direction. These environments will speed up the kill chain process: Find, Fix, Track, Target, Engage and Assess (F2T2EA). Other relevant programs include the USAF's Interim Capability for Airborne Networking (ICAN) and the Joint Capability for Airborne Networking (JCAN) programs that are designed to manage airborne radios (primarily), to permit both digital and voice communications to share valuable radio frequency (RF) bandwidth. The USAF's Operational Information Management (OIM) program has been investigating and developing many of the software tools and techniques for building a Net-Centric capability for the military where COIs can publish, subscribe, and search for information objects (IOs) using the GIG infrastructure.

The military is addressing many of the issues addressed above to the extent that they have developed secure phones for the distribution and reception of classified information. Two phones exist today that meet some of the military's requirements, i.e. General Dynamics' Sectra Edge and the L-3 Guardian.

Even with all this technology we are still limited in retrieving and providing the right information to the soldier in the field because of their terminal device, the size of the information objects, and the limited bandwidth available. To solve some of these problems the communications community has relied on information theory. In section two we provide a brief

review of information theory. Section three will present a method for obtaining a user's perception of the amount of information contained in images. Section four will discuss how this information can be used to modify images before they are encoded (using information theory) based upon the terminal devices and the bandwidth available. Section five will present a summary, conclusions and future work.

Section Two Information Theory

Information theory has allowed us to compress large information objects and send them efficiently over different communications channels e.g. telegraph, radio, television, digital radios, and now the Internet. We use information theory based compression/encoding algorithms to modify information objects to maximize the use of a channel's capacity. This approach requires that we spend computational resources on the transmitter and receiver sides of the channel to maximize the usage of the channel. See Figure 1.

Figure 1 Classical Communication Diagram

It was discovered long ago that two symbol codes could be used to convey information such as long and short smoke signals and of course dots and dashes of Morris code. Today's digital computers are the epitome of using two symbol codes to represent data for all its computations and for data and information creation, modification, and transmission.

To understand the basics of information theory and compression and how it relates to our work let's consider some early publications in this area. In [1] a history of information theory is provided where the author refers to Hartley who defined information:

"as the successive selection of symbols or words, rejecting all "meaning" as a mere psychological factor, and showed that a message of N symbols chosen from an alphabet or code of S symbols has S^N possibilities and that the "quantity of information" H, was most reasonable defined as the logarithm, that is H = NlogS."

It is intuitive, that if there are S equally likely symbols that can be chosen for creating a message of N symbols long then there exists S^N possible unique permutations. The probability of obtaining or choosing one of these messages is 1/ S^N or S^{-N}. It follows that information is directly related to probability which is a mathematical approach for dealing with uncertainty. Considering that information is related to uncertainty, e.g. if someone tells you something that you already know is true (e.g. 2 + 2 = 4) then they have provided you no information. Therefore the higher the probability of an event will occur then the less the information it conveys or stated by Cherry [1] "the information conveyed by a symbol must decrease as its probability increases".

If we continue with the above example and let the space of symbols equal two, i.e. S = {a,b} and the number of symbols to be transmitted is also two i.e. N = 2 then the event space consists of all possible messages i.e. E = { (a,a), (a,b), (b,a), (b,b)}.

Let us now define a random variable X = -log(p) over the event space E describing the mutually exclusive events of the outcomes of a random experiment i.e. E = { E_1, E_2, . . . , E_M}, where M is the total number of events. To each event E_i there corresponds a value x_i of the random variable X such that x_i = -log P{E_i} = -log(p_i) or $p_i = P\{X = x_i\}$. In our simple case above M = S^N or 4 and since we are assuming equally likely events then the probability of any one of these events is 1/ S^N or S^{-N} or in our case 0.25.

Computing the average information as the expected value of a random variable X we obtain

$$H(X) = -\sum_{i=1}^{M} p_i \times \log_2(p_i).$$

Where for our simple case H(X) = 2.0 which is a maximum since each of the events are equally likely.

The average information per message, H(X), is also called the entropy of the source and is denoted by the letter H. If we have only two different letters that can be transmitted with probabilities p and (1-p) then the plot of the average information is shown in Figure 2. It can be seen that the maximum entropy exists when the probability of both letters being transmitted are equal i.e. ½ and the value of H is 1, or that the average information per letter is a maximum of one bit per letter.

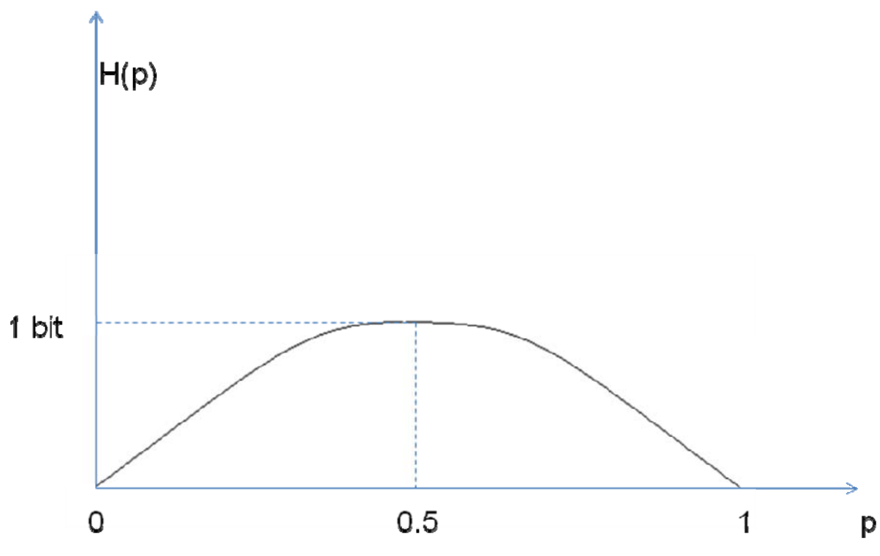


Figure 2 Entropy of an Independent Binary Source

Information theory is the basis for many of the compression algorithms used today in digital communications. The expected length of messages is one measure of efficiency for an encoding algorithm. An approach taken is to encode and decode the letters/symbols into a finite message in a one-to-one mapping to a finite binary bit stream. From [3] encoding is defined as a procedure for associating words constructed from a finite alphabet of one language with given words of a second language in a one-to-one manner. Decoding is to perform the inverse operation between the second language to the first language. If we assume, for example that the one-to-one mapping is to the binary domain then the expected length of a message is:

$$\overline{L} = \sum_{i=1}^{N} (p_i) \times n_i$$

where n_i is the number of binary characters to express message i. Efficiency is defined by [3] for a binary coding scheme to be the information divided by the expected length of a message i.e. $H(X)/\overline{L}$. The more efficient the coding scheme then the less bandwidth is required to convey information. For our simple example let us define a coding scheme where (a,a) maps to 00, (a,b) maps to 01, (b,b) maps to 10, and (b,a) maps to 11. Computing $\overline{L} = \sum_{i=1}^{N} (p_i) \times n_i$ yields 2 and the efficiency is equal to 1 or 100% for our simple example. For a more detailed description of information theory there are numerous books and papers available, two of these are [3, 4].

Not explicitly discussed in this work are the transmitting and receiving devices connected to the communication's channel, nor the information object itself. This was recognized early on in information theory, according to Cherry [1] "It is important to emphasize, at the start that we are not concerned with what is being communicated; the meaning or the truth of a sentence is outside the scope of mathematical "information theory". The emphases is made even stronger by Weaver [2],

"Weaver plausibly divided the problem of communication into three levels.
Level A: How accurately can the symbols of communication be transmitted? (The technical problem.)
Level B: How precisely do the transmitted symbols convey the desired meaning? (The semantic problem.) .
Level C: How effectively does the received meaning affect conduct in the desired way? (The effectiveness problem)"

Information theory addresses Level A. In the work presented here we are addressing Level B and Level A. We wish to develop methods to subjectively measure Level B i.e. maintain the intended information of the original information object but yet reduce its size. By so doing we are assuming the compression algorithms developed using information theory are capable of maintaining the quality of the information objects. We wish to partition information objects into their respective components and determine how we can reduce the amount of data required to convey their intent or meaning and yet maintain the amount of information desired.

The key is that we need to modify an information object not just because of the channel bandwidth and noise but also based upon the device that is generating the information object and also the device receiving the information object hence the use of ontologies and the necessity of subjectively defining what is acceptable for conveying the intended information.

Section 3 Modifying Information Objects

There are numerous organizations that are addressing the adaptation or the modification of information objects for mobile devices. One interesting article is [5]. Our approach is slightly different in that we eventually would like our system to dynamically change IOs based upon a user's quality of experience and the status of the communications channel. In this section we wish to describe how we are creating quality curves that will be used in our optimization engine for modifying these IOs on the fly. The information objects we are concerned with are the written word, images, video, and audio. An image's basic attributes and quality are based upon the original image. We are not currently interested in enhancing an image and increasing its quality. For this work we are assuming that the original image is the maximum quality or has a maximum score of 100. Given an image there are two attributes we can easily vary, before compressing the image, to reduce its size and yet attempt to maintain its information. Consider the four images below in Figure 3. The original and larger image on the right is 256 by 256 pixels in size with 24 bit color. The image to its left has been reduced to 75% of its original size or 192 pixels by 192 pixels with 24 bit color. The following two images are reduced in size to 50% and 25% of the original size with 24 bit color. The scale on the x axis represents the sizes of the images relative to the original and the y axis represents hypothesized values of quality, in percent, that a general user would choose to quantify the images. The curves were created using a polynomial curve fitting algorithm. Consider Figure 4 where we have varied the color depth of the same full scale image. The constructed curve in Figure 4 is similar to the previous figure. The images shown are for 24 bit, 8 bit, 4 bit and 2 bit color depths. The 16 bit color depth image is not shown.

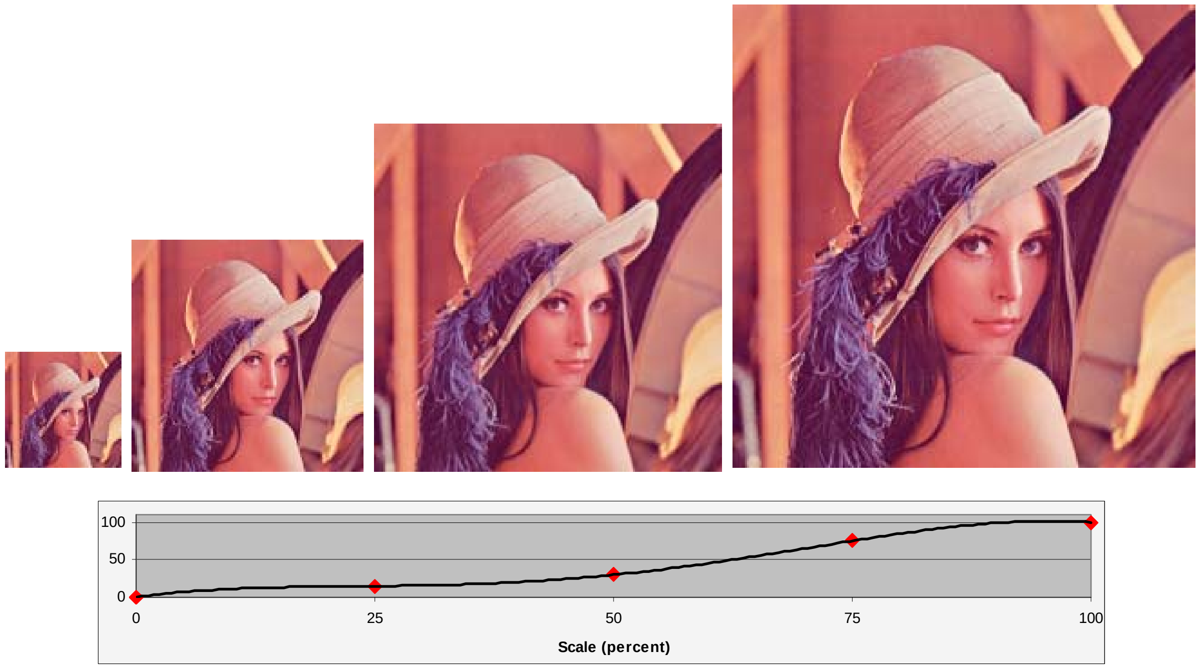


Figure 3 Creating a Scale Quality Curve

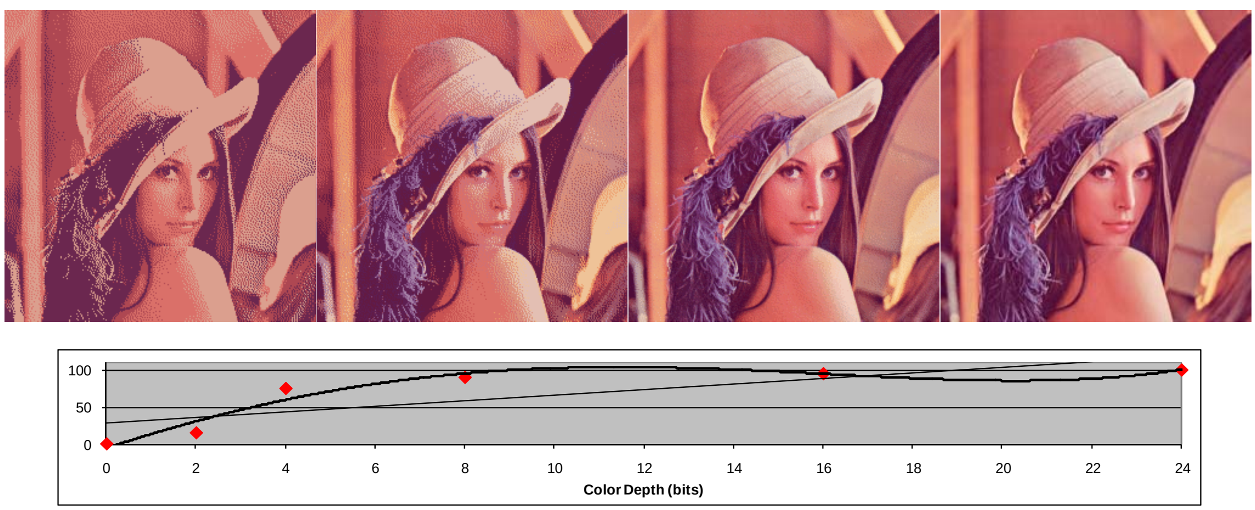


Figure 4 Creating a Color Depth Quality Curve

Studying the above images and curves one recognizes that the original image can be reduced substantially without deteriorating the quality appreciably and yet they still may convey the required amount of information. If we now consider information theory and address the encoding algorithms, there are lossless compression and lossy compression algorithms. The first image on the right in Figure 5 is without compression. The next figure on the left is 50% compression, followed by 15% and 5% lossy compression using the JPEG format. The compression is obtained by decreasing the accuracy of the quantization used in the higher frequencies of the

image. If an excessively low quality is used (i.e. low percent such as 5%) then the high frequency components are discarded completely.

Our approach is modifying the classical communication approach shown in Figure 1 with the process chain shown in Figure 6. In this chain we will modify the images, i.e. choose the size and color depth based upon the receiving device, the channel bandwidth, and the composite quality factor dictated by the end user. By changing the users' quality of experience, software algorithms will modify the image and select the proper encoder and it's settings to meet the user's requirements. The encoders shown in Figure 6 represent different lossy and lossless encoders, along with their settings such as ImageMagick, ffmpeg, Open Text Summarizer, etc.

Figure 5 Creating a JPEG Lossy Compression Quality Curve

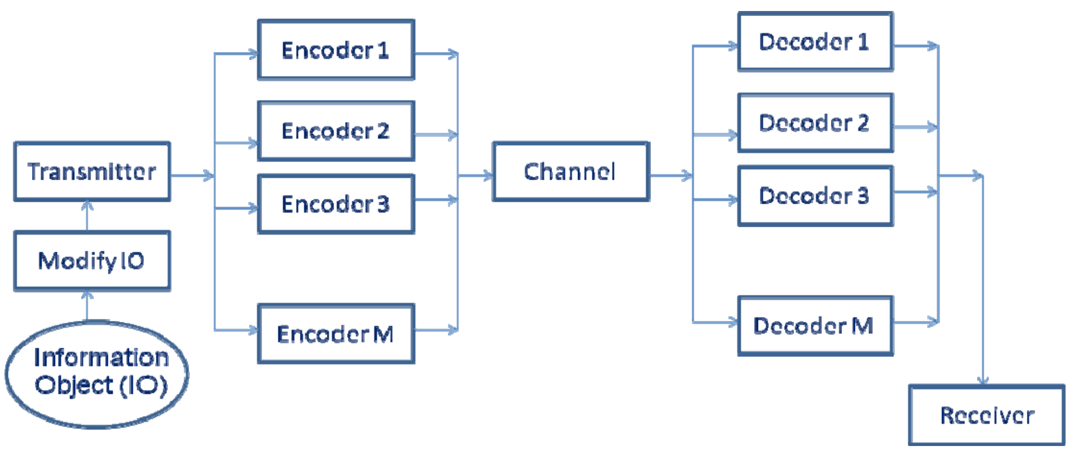


Figure 6 Modified Communication Diagram

Section 4 How to modify information objects (images).

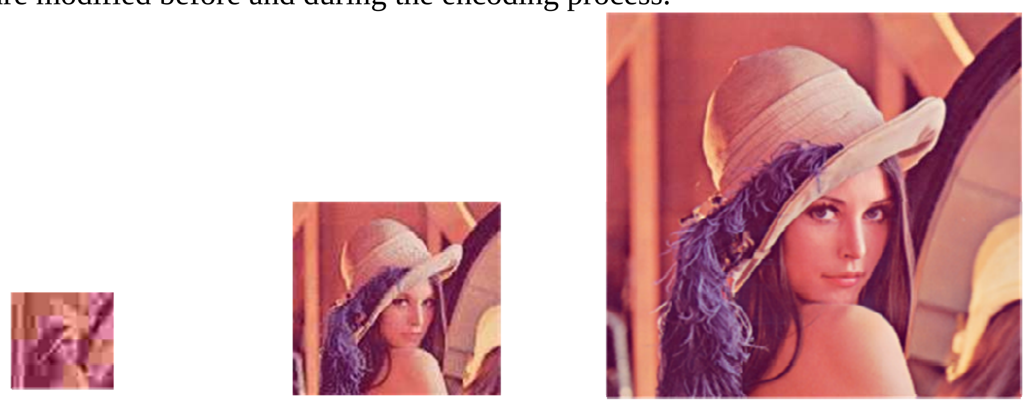
The subjective quality curves discussed above will be used in conjunction with attributes describing the communications link, the user's quality of experience specifications and the attributes describing a user's communications device to decide how to modify IOs. Currently we are obtaining a device's information from an open source project called WURFL (Wireless Universal Resource File) and this information is stored in an ontologically based XML file. The WURFL project catalogs thousands of mobile devices and contains information such as what image, audio and text formats the device can support, what the device's screen resolution is and what services are provided by the manufacturer. With this device information decisions on how to reduce the size of the information object for the users' device constraints can be made. For example, if a user's device only displays 256 colors, there is no reason to waste resources in sending an image with a color depth of 65,565 colors. Similarly, if a device can only display a resolution of 320x220 pixels then we should shrink the images to 320x220 pixels or less. Mobile devices also have a limit on how many characters they can display at any one time, the WURFL database includes this information and should be used to set bounds for modifying textual information objects.

In the future we will provide the mobile user the option to receive information objects at multiple levels of quality. For example, if an image size is reduced and data the user might be interested in is lost, the user will have the option to request a higher quality while understanding that the download time will increase. The server can use the user's feedback to provide a new information object based upon the original with the new preferences. This process can be iterative until either the end user receives the content that meets their needs or the limitations of the device have been exceeded. As a result, this gives the end users control of the quality of the information objects they receive as well as better utilizing the resources of both their device and network.

To illustrate our approach consider the following two examples. The image on the left in Figure 7 is the original image (shrunk to 25% to fit the space constraints of this paper) requiring 1.3 MegaBytes of data to describe its contents. The transcoded/modified figure on the right is shown 100% in size and requires only 5.14 KiloBytes to describe its contents. Over a hypothetical communications channel of 200Kbits/Second (e.g. EDGE network) the image on the left would require over 52 seconds to be delivered and the one on the right would take 0.2 seconds. Both images transmit the "same" amount of information, i.e. we view Secretary Gates speaking at the Pentagon. The bottom line is: it is not the data size that counts but the quality, as perceived by the end user, of the information delivered.

Figure 7 Secretary Gates

Consider the images shown in Figure 8. It can be seen that seven or more seconds to retrieve an image on the EDGE network may be too long to wait and 0.02 seconds is very fast, however the quality of the image and the information being conveyed may be unacceptable. Waiting 0.12 seconds is more than likely acceptable and all the information appears to be present. It is our intention to use quality curves as discussed above along with quantitative measures to control how IOs are modified before and during the encoding process.



Unacceptable Quality	Acceptable Quality	Original
64 x 64 pixels	128 x 128 pixels	256 x 256 pixels
5% JPEG Quality	50% JPEG Quality	100% JPEG Quality
Approx Size 413 Bytes	Approx Size 3 Kbytes	Approx Size 197 KBytes
Transmission Time	Transmission Time	Transmission Time
Over the Edge Network	Over the Edge Network	Over the Edge Network
0.02 seconds	0.12 seconds	7.88 seconds

Figure 8 Hypothetical Use of Quality Curves

Section 5 Summary, Conclusions and Future Work

The major thrust of our work is to deliver and receive information from computational devices with limited bandwidth and processing capability. This paper has documented an approach for extending communications and mathematical information theory to include the meaning of information objects (IO). We have attempted to make the case to extend the encoding process of an IO to the semantic domain as recorded by Pierce [2]. In making our case we have used images as one information type or format. We need to develop quality curves for text, images, audio and video formats and integrate these results with quantitative measures to dynamically change an IO based upon an individual's quality of experience, i.e what is acceptable for them given their time constraints and the information they require.

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References

1. E. C. Cherry, "A History Of Information Theory" in Proc. Inst. Elec. Eng. (London), Vol. 98, Pt. 3, pp. 383-393, Sept. 1951.
2. J. R. Pierce, "The Early Days of Information Theory", IEE Transaction On Information Theory, Vol. IT-19, No. 1, January 1973.
3. F. M. Reza, "An Introduction to Information Theory", McGraw-Hill Book Company, New York, Toronto, London, 1961.
4. C. E.. Shannon, " The Mathematical Theory Of Communication," Bell Syst. Tech. J., vol. 27, pp. 379-423, July 1948; also ibid., vol. 27, pp. 623-656? Oct. 1948.
5. W. Y. Lum andF. C. M Lau, "A Context-Aware Decision Engine for Content Adaptation", Pervasive Computing, IEEE, 2002.